

Carbon Sequestration Through Reforestation in Reclaimed Coal Mine Sites in East Kalimantan, Indonesia.

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Abstract.

Forests absorb CO_2 during photosynthesis and store it as organic matter in biomass plants. The amount of organic matter stored in forest biomass per unit area and per unit time is the subject of forest productivity. Forest productivity is a picture of the ability of forests to reduce CO_2 emissions in the atmosphere through physiological activity. Measuring productivity of forests in the context of this study is relevant to biomass measurements. Forest biomass provides important information in the assumed magnitude of potential CO_2 sequestration and biomass in a certain age that can be used to estimate forest productivity.

Reclamation of former coal mine is an attempt to repair or restore the land and vegetation in forest areas damaged as a result of mining activities, in order to function optimally as intended. Measurement of forest productivity in vegetation of areas mined coal is the purpose of this study.

Tree biomass accumulations and age-related changes of *P. falcataria* plantations were determined using a destructive sampling technique. These data were used to estimate optimum harvesting time. Tree biomass samples were collected in 3, 5, and 7 year old plantations in mined area, and in 7 year old plantations in not mined area. About 10 trees were sampled from each stand. Tree growth characteristics were evaluated for both sites.

Allometric equations were developed for each site to estimate root, stem, branch, leaf, aboveground and total biomass and stem volume. Using these equations, the stem volume and biomass of each component for each stand age were estimated. A single allometric relationship for all sites was found just for estimation of biomass and stem volume.

Keyword : *P. falcataria*, reclamation, East Kalimantan, biomass, CO_2, allometric equations

1. Introduction.

The Kyoto Protocol recognized that afforestation and reforestation could be counted as potential carbon sinks and are therefore useful practices for achieving pledged greenhouse gas emission reductions. The Marrakesh Accords ratified these forestry activities within the Clean Development Mechanism project (AR-CDM). Therefore, AR-CDM could act as a stimulus to enhance sustainable forestry development and contribute to the recovery of forests that have been disturbed and destroyed. (Heriansyah, I, 2006), (Diana,R,2002), (Hiratsuka,M,2004).

Carbon dioxide (CO_2) is a greenhouse gas and as it serves to trap heat in the atmosphere, causing global warming and climate change. The concentration of CO_2 in the atmosphere increased dramatically since the beginning of the industrial revolution, which based on measurements at the Mauna Loa atmospheric CO_2 increased from 315.98 ppm in 1959 to 385.34 ppm in 2008 (Keeling and Whorf, 2009). The main cause is the burning of coal and oil, and deforestation followed by recent increases.

Biomass is the total weight or volume of organisms in a given area or volume, biomass is also defined as the total amount of living matter on the surface of a tree and stated tones dry weight per unit area (Brown, 1997).

Forest productivity is a description of the ability of forests to reduce CO_2 emissions in the atmosphere through physiological activity. Measuring productivity of forests in the context of this study are relevant to biomass measurements. Forest biomass provides important information in the assumed magnitude of potential CO_2 sequestration and biomass in a certain age that can be used to estimate forest productivity (Hairiah K, et.al.2007).

Measurement of planted forests is necessary to understand growth characteristics and to estimate the quantity of carbon sequestered by a forest. Allometry is an effective method for accurately estimating the biomass of trees, tree components and stands (MacDicken 1997).

Paraserianthes falcataria with common or scientific names it is known, *Paraserianthes falcataria* (L.) Nielsen, is a valuable multipurpose tree for the humid tropics. One of the fastest growing of all tree species, it is used for pulp and other wood products, fuelwood, ornamental plantings and shade for coffee, tea and cattle. Potential uses for which it is being tested include alley farming and intercropping in forest plantations.
"Falcataria" belongs to the Leguminosae (subfamily: Mimosoideae). It is most widely known by its former name, *Albizia falcataria* but it also has been called *A. moluccana* and *A. falcata*. "Falcate' means "curved like a sickle," referring to its leaflets. Leaves are alternate, bipinnately compound, and 23-30 cm long. Flowers are creamy white, and pods are narrow, flat, 10-13 cm long and 2 cm wide. This is a large tree that regularly reaches 24 to 30 m in height and 80 cm in diameter. When grown in the open, trees form a large, umbrella-shaped canopy. Crowns are narrow when this light-demanding species is grown in plantations of 1,000 to 2,000 trees/ha. Trees regularly produce large quantities of seeds after reaching 3 to 4 years of age.

P. falcataria occurs naturally in Indonesia, Papua New Guinea, and the Solomon Islands from 10^o S to 30^o N. In its natural habitat it grows from sea level to 1,200 m above sea level with an annual rainfall from 2,000 – 4,000 mm, a dry season of less than 2 months, and a temperature range of 22^0 to 34^0 C. Although it is likely to perform better on alkaline soils there are many examples of it growing well on acid soils (NAS 1983).

P. falcataria is as erosion control, pure stands give a good protective cover to prevent erosion on slopes and are recommended in the Philippines for this purpose on catchment areas sheltered from typhoons. Shade or shelter: The plant is extensively planted in Southeast Asia as a shade and nurse crop for coffee, cocoa, tea, other crops and young timber plantations. Its fast growth and good shading properties outweigh the disadvantages of its sensitivity to strong winds and its relatively short life. Reclamation: Plantations of *P. falcataria* have been established even on tailings left after tin mining. It is planted extensively for reforestation and afforestation of denuded and eroding land. Nitrogen fixing: Nodulates and fixes atmospheric nitrogen. Soil improver: The natural drop of leaves and small branches contributes nitrogen, organic matter and minerals to upper layers of soil. The plant's extensive root system further improves soil conditions by breaking up soils to provide channels for drainage and aeration. Ornamental: Suitable as an ornamental, although its brittle branches can be a problem in windy areas.

The objectives of this study were to compare growth characteristics and biomass accumulations of *P. falcataria* obtained from two different site and to evaluate the possibility of formulating a single allometric equation, and to estimate optimum rotation of *P. falcataria* plantations in East Kalimantan, Indonesia.

2. Material and Methods.

2.1.Study Sites.

The study was conducted during March to September, 2009 in *P. falcataria* plantations in coal mining concession area of "Multi Sarana Avindo Coal Mining Company", East Kalimantan, Indonesia. Field surveys in were conducted in four *P.falcataria* plantation sites with stand ages of 3, 5, and 7 years (three plots in mined areas and one plot in not mined area).

The area is locate at longitude 117^O.03'55" East and latitude 0^O.37'30" South and at elevation 40 – 50 m above sea level (asl), where the annual rainfall is 2.000 mm and annual temperature range between 25^OC – 33^OC. The soil is a red-yellow podsol and the terrain is flat to undulating.

2.2.Plot Setting.

Three 0.06 ha plots (20 × 30 m) for each stand age were established to evaluate tree growth characteristics and to estimate forest biomass. Stem diameter at breast height (D; 1.3 m above ground) and tree height (H) were measured for all *P. falcataria* trees in the plot. D was measured using callipers for trees with small D or a diameter tape for trees with large D. H was measured using an ultrasonic hypsometer for heights > 12 m and a measuring rod for heights < 12 m.

2.3.Estimation of Tree Biomass.

To formulate allometric equations for trees, about 10 different D-sized (trees > 2 cm in diameter) trees were cut down around the plots.

In total, 12 trees were sampled. After felling and completely unearthing the root system, a sample tree was separated into each component as logs: 0–0.3 m, 0.3–1.3 m, 1.3–3.3 m, etc. every 2 m to the top, and was divided into living branches and twigs, dead branches and twigs, leaves and roots. Tree height, diameter of the logs and weight of tree components of the sample trees were measured in the field. Sub-samples were brought to the laboratory to record the oven-dry weight. Fresh samples were dried at 105°C in a constant- temperature oven. Drying of leaves and wood biomass < 10 cm in diameter required two days, whereas wood biomass > 10 cm diameter required four days. Ratios of dry /fresh mass were calculated and used to convert fresh mass into dry mass. In this study, allometric equations to estimate tree component biomass and stem volume of *P.falcataria* plantations at each site were established using D and H. We devised equations applicable to each individual stand using the following allometric relationship: $Wi = a (D^2H)^b$; where a and b are constants, D is tree diameter at breast height (cm), H is tree height (m), and Wi is the amount of biomass of component i (kg) or stem volume (m^3).The aboveground biomass was determined by calculating the sum of the biomass of the stem, branch and leaf. Total biomass was calculated as the sum of aboveground biomass and root biomass (Heriansyah, et. al.2007).The total biomass in each plot was calculated from the summed biomass of all trees in the plots. These data were converted into hectares.

3. Results and Discussion.

3.1.Stand Growth of P. falcataria.

Growth and development of stands *P. falcataria* in each stand age class 3, 5 and 7 years in mined areas and areas not mined are listed in Table 1.

Table 1. Stand growth of *P. falcataria* on mined areas and not mined areas.

Stand age	Mean Diameter	Mean Heigth	Volume ha^{-1}	Bassal Area ha^{-1}	MAI	Remark
(years)	(cm)	(m)	($m^{3)}$	($m^{2)}$	($m^{3)}$	
7*	26.10	8.0	259.49	29.15	37.07	not mined
7**	21.25	7.0	126.99	27.89	18.14	mined area
5**	19.58	6.0	95.65	22.37	19.13	mined area
3**	14.96	5.0	57.90	16.89	19.30	mined area
*= not mined area; ** =mined area; MAI = Mean Annual Increment						

There is a real difference between standing on the areas not mined area by the mined area. From the data obtained shows that the volume per hectare in age 7 years, the area was not mined 259.49 m^3 whereas the former mining areas only 126.99 m^3. If calculated MAI in areas not mined is 37.07 m^3 while the MAI for mined areas is 18.14 m^3. Volume per hectare or MAI in not mined areas much bigger than the mined areas. This occurs because the soil conditions at the mined area has changed, which mined areas of land already degraded.

3.2 Allometric Equation.

Allometric equations resulting from the relationship between the diameter breast heigh and stem volume for *P. falcataria* stands presented in Fig.1. The Fig. 1. Is a graphic illustration of the allometric equation

$Y = 0.00003 X^{2.7874}$ with $R^2 = 0.9845$, which is the relationship between tree diameter at breast height of *P. falcataria* by volume.

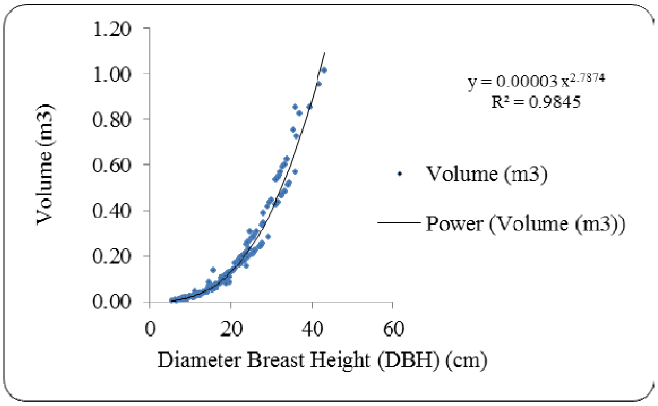

Fig1. Allometric equation the relationship between volume and DBH stand of *P. falcataria.*

3.3.Biomass in Revegetation Area.

The largest part of carbon exchange (CO_2 and CO) between the atmosphere and the land occurred in the forest because forest vegetation to absorb carbon through photosynthesis to build the other half of woody biomass is carbon compounds. Thus the status of forest management will determine whether the land acts as a source of emissions (source) or sinks (sinks) of carbon.

Furthermore, Fig. 2. Shows the relationship between diameter at breast height (DBH) with tree biomass for *P. falcataria* where allometric equation for stem is $Y = 0.3328\ X^{1.8549}$ with $R^2 = 0.9877$, for the branches is $Y = 0.4406\ X^{1.4344}$ with $R^2 = 0.9014$ and for the leaf is $Y = 0.4064\ X^{1.265}$ with $R^2 = 0.9498$. When you see its R^2 value, then there is a close relationship between the diameter at breast height with biomass where the value is more than 90%.

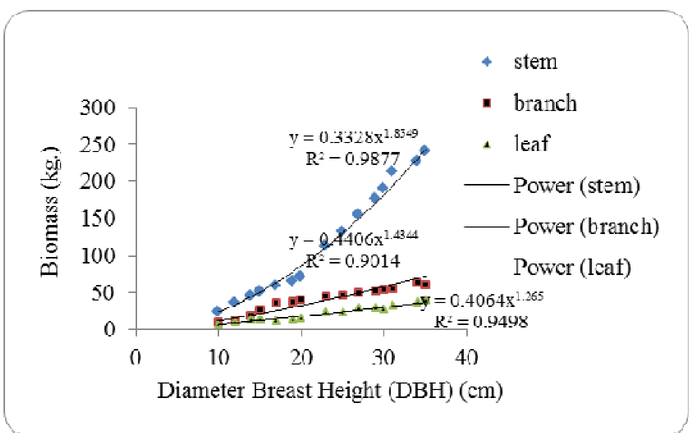

Fig. 2. Allometric equation relationship between biomass and DBH stand of *P. falcataria.*

Percentage of all tree components of biomass that stems, of branches and leaves are very variable, the percentage of stems biomass was 64 %, branches biomass was 22 %, and leaf biomass was 14%. (Fig. 4)

The recapitulation of biomass for each age class are listed in table 2.

Table 2. Stand biomass *P. falcataria* in different age classes.

Age Class	Volume ha^{-1}	Bassal Area ha^{-1}	Biomass			Total
			Stem	Branch	Leaf	
(year)	(m^3)	(m^2)	Mg ha^{-1}			
7*	259.49	49.15	128.90	42.84	22.73	194.46
7**	126.99	27.89	75.37	27.45	15.15	117.97
5**	95.65	22.37	61.08	22.86	12.73	96.67
3**	57.90	16.89	47.94	20.01	11.63	79.58
*= not mined area; **=mined area						

Table 2. It appears that biomass is not mined areas showed a higher biomass than biomass in mined areas. At seven years of total biomass was 194.46 mg ha^{-1}, while in the mined areas of the same age was 117.97 mg ha^{-1}. This indicates that the biomass at mined area apparently around 60% lower than the biomass in areas not mined.

3.4.Root biomass.

Equation to obtain estimates of root biomass (root biomass density) include equations composed by (Cairns et al. 1997) in Sutaryo, Dandun,(2009).

RBD = exp (-1.0587 + 0.8836 x ln AGB)

RBD = root biomass density (Mg ha^{-1}), AGB = Above Ground Biomass (Mg ha^{-1}).

Root biomass estimates are based on total AGB are presented in Table 3, the table contains data total AGB, root biomass and total tree biomass for each type of stand overall and each age class, and biomass in areas not mined and mined areas.

Table 3. root biomass and total tree biomass *P. falcataria.*

Age	Biomass					
	Stem	Branch	Leaf	AGB	Root	Total
(years)	($Mg.ha^{-1}$)					
7*	128.90	42.84	22.73	194.46	36.53	230.99
7**	75.37	27.45	15.15	117.97	23.49	141.45
5**	61.08	22.86	12.73	96.67	19.70	116.37
3**	47.94	20.01	11.63	79.58	16.59	96.16
*=not mined area; ** = mined area; AGB = Above Ground Biomass						

Carbon Content and Absorption of CO_2.

Forests play a role in improving the absorption of CO_2 in which with the help of sunlight and water from the soil, vegetation chlorophyll to absorb CO_2 from the atmosphere through photosynthesis. Result of photosynthesis, among others, are stored in the form of biomass that makes vegetation grow bigger or higher. This growth will continue until the vegetation is physiologically stop growing or harvested. In general forest "net growth" (especially of trees were growth phase) were able to absorb more CO_2, while the mature forest with a small growth just store carbon stock but can not absorb excessive CO_2 (Kyrklund, 1990). With the existence of the forest, the number of carbon (C) stored the more and longer. Therefore, planting vegetation on empty land or rehabilitate degraded forests will help to absorb the excess CO_2 in the atmosphere.

By using allometric equation of the relationship between the diameter at breast height and total biomass, total carbon is derived from the value of biomass, shown in table 4. Table 4 is obtained by using the approach proposed by the (JIFFRO, 2000) in which the carbon content of forests constitute 50% of the forest biomass. (Murdiyarso,2004), (West , 2009)Carbon content for each tree component and total CO_2 absorp by plants of each type are presented in Table 4.

Table 4. Total carbon absorption by *P.falcataria* results of revegetation.

Stand Class Age	Biomass			Co_2 Absorption		
	AGB	Root	Total	AGB	Root	Total
(years)	Mg ha-[1.]					
7*	194.46	36.53	230.99	97.2	18.26	115.50
7**	117.97	23.49	141.45	58.98	11.74	70.73
5**	96.67	19.70	116.37	48.34	9.85	58.19
3**	79.58	16.59	96.16	39.79	8.29	48.08
*=not mined area; **=mined area; AGB =Above Ground Biomass						

Table 4. shows an increase in carbon absorption as the increasing stand age. The potential of plantations to absorb CO_2 from the atmosphere varies according to the species, its age and stand density. CO_2 uptake by the stand could be increased if the silvicultural treatments applied in the area of mined revegetation. Many potential silvicultural treatments might be used to change, accelerate change, or maintain tree and stand conditions. Those that are typically used to foster improved tree growing conditions and or improved growth and yield include: choice of species and site, site preparation, planting, spacing, weeding & cleaning, thinning , pruning, fertilization, logging slash distribution. The combination of treatments used in a silvicultural system can have large impact on growth and future yields. For example, a stand managed with all of the above treatments may produce as much as four times the yields of the region wide average of such stands without treatment. (Alan R.Ek, 2007).

4. Conclusion.

Base on the results of this study concluded that :

1. Allometric equations in this study can be used to estimate stem volume and biomass stands of the same species, without having to cut down trees (destructive).
2. Diameter of plant is an accurate estimator in formulating of allometric equations for estimating stem volume and biomass plants *P.falcataria* forest in East Kalimantan.
3. One of the functions of forests is controlling the climate by absorbing CO_2 from the atmosphere and stores it in the form of organic matter in plant biomass.
4. Carbon sequestration rates vary by tree species, soil type, regional climate, topography and management practice.
5. Silvicultural treatments, might be used to change, accelerate change, or maintain tree and stand conditions.

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Fig. 3. Location of study site in Indonesia. **x** in the circle is the study area.

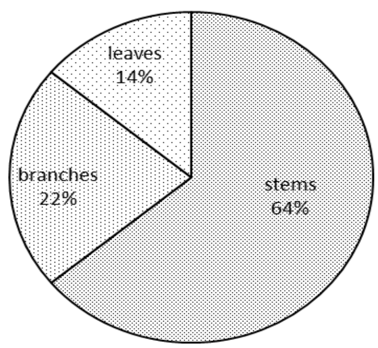

Fig. 4. Biomass storage of different components stems, branches and leaves.

Table 5. Allometric equations used to estimate volume and biomass of *P. falcataria* using DBH.

DBH	Volume	Biomass				Carbon			
		Stems	Branches	Leaves	Total Biomass	Stems	Branches	Leaves	Total Carbon
(cm)	(m^3)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
10	0.018	23.82	11.98	7.49	43.30	11.91	5.99	3.74	21.65
12	0.030	33.41	15.56	9.44	58.42	16.70	7.78	4.72	29.21
14	0.046	44.47	19.41	11.48	75.37	22.23	9.70	5.74	37.68
16	0.068	56.97	23.51	13.59	94.08	28.48	11.75	6.79	47.04
18	0.094	70.89	27.84	15.78	114.51	35.44	13.92	7.89	57.25
20	0.126	86.19	32.38	18.03	136.61	43.09	16.19	9.01	68.30
22	0.165	102.85	37.13	20.34	160.33	51.42	18.56	10.17	80.16
24	0.211	120.87	42.06	22.71	185.65	60.43	21.03	11.35	92.82
26	0.263	140.22	47.18	25.13	212.54	70.11	23.59	12.56	106.27
28	0.324	160.88	52.47	27.60	240.97	80.44	26.23	13.80	120.48
30	0.393	182.85	57.93	30.12	270.91	91.42	28.96	15.06	135.45
32	0.470	206.10	63.55	32.69	302.35	103.05	31.77	16.34	151.17
34	0.557	230.63	69.33	35.30	335.27	115.31	34.66	17.65	167.63
36	0.653	256.43	75.25	37.95	369.64	128.21	37.62	18.97	184.82
38	0.759	283.48	81.32	40.64	405.45	141.74	40.66	20.32	202.72
40	0.876	311.7772	87.53	43.36	442.68	155.88	43.76	21.68	221.34